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THREE-DIMENSIONAL CONE BEAM COMPUTED TOMOGRAPHY STUDY OF PHARYNGEAL AIRWAY DIMENSIONS IN DIFFERENT ANTEROPOSTERIOR SKELETAL CLASSIFICATION PATIENTS

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10 July 2015

Three-dimensional Cone Beam Computed Tomography Study of Pharyngeal Airway Dimensions in Different Anteroposterior Skeletal Classification Patients

A THESIS

Presented to the Faculty of

Uniform Services University of the Health Sciences

In Partial Fulfillment

of the Requirements

For the Degree of

MASTER OF SCIENCE

By

David Terry Ensley, BS, DMD

San Antonio, TX

June 1, 2015

THREE-DIMENSIONAL CONE BEAM COMPUTED TOMOGRAPHY STUDY OF PHARYNGEAL AIRWAY DIMENSIONS IN DIFFERENT ANTEROPOSTERIOR SKELETAL CLASSIFICATION PATIENTS

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DEDICATION

This thesis is dedicated to my family. Without their support, I could not have made it this far. Thank you to my beautiful wife, Mary, for walking beside me every step of the way through the hard work of dental school and residency. Your encouragement and love has meant so much to me. Thank you to Laura and Daniel for always putting a smile on my face when I come home each day. Thank you to my mother for her countless hours of hard work and sacrifice while educating and raising me. Thank you to my father for providing an incredible role model of what it means to be a man—hard work, integrity, compassion, and putting family first. Together you made possible the opportunities I enjoy today. Most of all, I thank my Lord and Savior Jesus Christ for his many blessings—may he receive all the praise and glory.

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ABSTRACT

Introduction: Our objective was to determine whether the airways of Class I and II patients differ in size. **Methods:** 100 pretreatment CBCT images were randomly selected, divided into Class I and II groups, and lateral ceph images were sectioned from the CBCT's. Using the Dolphin airway tool all the airways were measured at two thresholds. **Results:** There was no statistical difference between the airway volume, sagittal area or minimal cross sectional area between the Class I group and the Class II group ($p>0.05$). There was a large variation in airway sizes. The airway areas of high angle Class II patients were significantly smaller than the Class I group ($p=0.045$). **Conclusions:** Airway sizes are highly variable and do not differ between Class I and II patients, except for high angle Class II patients who have smaller airways than Class I.

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I. BACKGROUND AND LITERATURE REVIEW

A. Background

As a specialist in craniofacial development, the Orthodontist has the ability to evaluate the relationship between the facial skeletal pattern and its surrounding soft tissue structures. A routine portion of every orthodontist's exam is to determine a patient's skeletal Classification. The focus is often on the relationship between the skeletal anteroposterior (A-P) pattern and the dental Angle Classification, but other information can also be gained from the patient's skeletal pattern.

A number of research articles have shown that the patient's skeletal A-P Classification, as determined by a 2D lateral cephalogram, is correlated with pharyngeal airway space. In a study of 90 adolescent subjects, Ceylan and Oktay found that oropharynx area became smaller with an increase in the ANB angle[1]. In other words, Class II skeletal patients as judged by ANB angle had decreased airway dimensions. Another study completed in 2005 investigated the uvulo-glosso-pharyngeal dimensions in relation to A-P skeletal pattern[2]. They found that in Class II patients, the hyoid bone was closer to the mandible vertically and closer to vertebrae C3 horizontally compared to Class I patients. Class II patients have smaller inferior pharyngeal airway spaces. Nanda et al, divided 90 subjects into three categories based on ANB angle[3]. The upper airway decreased from Class III to Class I to Class II at the level of the nasopharynx and oropharynx.

One cause of skeletal Class II relationship is mandibular retrognathia. The position of the mandible has a profound effect on the pharyngeal airway due to the muscles attached to it, especially the tongue. Airway dimensions have been shown to correlate with mandibular size. Muto et al evaluated pharyngeal airway space at the level of the soft palate and the base of the tongue[4]. Mandibular retrognathic patients had smaller airways than normal and prognathic mandibles. The vertical growth of the mandible has been variously characterized as backward versus forward rotation, clockwise versus counterclockwise growth, and hyperdivergent versus hypodivergent pattern. A common characteristic of a backward rotating, clockwise growing, hyperdivergent mandible is that it results in a more posterior position of the anterior mandible than would be present if a similar sized mandible was normodivergent. Joseph et al showed that hyperdivergent facial patterns have pharyngeal airways that are narrower in an A-P direction compared to hypodivergent[5]. This relates well with the retrusive mandible commonly seen in hyperdivergent patients.

Until the development of Cone Beam Computed Tomography (CBCT), many studies on pharyngeal airway space (including all the studies previously mentioned) were limited by the 2D nature of a lateral cephalogram and the superimposition of anatomic structures on the airway space. A much more accurate picture of the airway volume is provided by CBCT[6]. CBCT has rapidly and enthusiastically been adopted by dental professionals. A variety of imaging machines and software are commercially available to practitioners to view, measure, and manipulate the airway in three dimensions. Weissheimer et al conducted an investigation into the accuracy of six different imaging softwares used to measure airway volumes[7]. All six imaging softwares reliably measured the volume of an oropharynx acrylic phantom scanned with an i-CAT scanner. Mimics, Dolphin3D, ITK-Snap and OsiriX had less than 2% error and were more accurate than InVivo Dental and Ondemand 3D, which had over 5% error. Additionally, the intra-rater and inter-rater reliability of airway measurements made on CBCTs was shown to be reliable in most dimensions[24].

The following studies all used CBCT to evaluate the pharyngeal airway. One method of analysis is to measure the area of maximum constriction of the airway, which Tso et al studied, finding that the area of maximum constriction was at the level of the oropharynx in 8 out of 10 patients studied[8]. The axial cross-sectional area varied from 90 mm^2 to 360 mm^2. Alves et al, studied upper airway space in Class II and III patients and concluded that the malocclusions did not affect the majority of airway spaces[9]. Iwasaki et al studied oropharyngeal airways in Class III compared to Class I patients[10]. They divided 45 children into Class I and Class III groups. Class III patients had larger and flatter oropharyngeal airways than Class I patients. Kim et al found that the total airway volume from the anterior nasal cavity and nasopharynx to the epiglottis was smaller in retrognathic patients than in patients with a normal anteroposterior skeletal relationship[11]. Claudinoa et al evaluated the pharyngeal airway of 54 adolescents divided into groups based on ANB angle using Dolphin Imaging software[12]. They found no association between skeletal pattern and the airway volume in the upper pharyngeal portion, nasopharynx, and hypopharynx. There was a negative correlation between ANB angle and airway volume in the lower pharyngeal portion and the velopharynx. A study by Grauer et al compared shape and volume of pharyngeal airways in different anteroposterior and vertical jaw relationships[13]. The volume of the inferior compartment of the airway was related to the anteroposterior jaw relationship, but not to vertical facial proportions. The shape of the airway, however was different between various vertical jaw relationships.

What clinical impact is associated with a decrease in pharyngeal airway in Class II skeletal pattern? Several studies have examined the correlation between cephalometric variables and Obstructive Sleep Apnea (OSA). Andersson et al found a reduced posterior airway and a posterior rotation of the mandible in patients with sleep apnea[14]. Both snoring and sleep apnea patients showed a reduction in AP dimension of the maxilla and mandible. These results differed from Zucconi et al and a recent study by Kurt et al that did not find a difference in cephalometric skeletal measurements between normal and obstructive sleep apnea patients[15, 16]. However, Kurt et al found that pharyngeal space in the soft palate area as well as the inferior pharyngeal space was lowest in OSA patients compared to controls. These results suggest that a causal link has not been established between the airway size associated with skeletal patterns and obstructive sleep apnea which is a multi-factorial disease process.

Orthodontists can directly influence the size of the airway through certain treatments they prescribe. Kirjavainen et al found that cervical headgear treatment in Class II malocclusions resulted in a wider retropalatal area while oropharyngeal and hypopharyngeal spaces remained more narrow than Class I molar controls[17]. Orthognathic surgery can also have a dramatic impact on the size of the airway. CBCT scans of patients with craniofacial malformations showed a significant increase in the volume of their airway after a LeFort III advancement[18]. Patients receiving maxillomandibular advancements for the treatment of obstructive sleep apnea also showed significant increases in all areas of their pharyngeal airways[19].

II. OBJECTIVES

A. Overall Objective

The objective of the study is to determine if there is a correlation between anteroposterior (A-P) facial skeletal Classification and the dimensions of the pharyngeal airway—specifically total pharyngeal airway volume, sagittal airway area, and minimum cross section area (MCA). This will help orthodontists better diagnose whether a patient's anteroposterior malocclusion may have an effect on their airway. It will also provide descriptive statistics on the average airway dimensions of non-growing orthodontic patients to provide reference values to compare airway measurements.

B. Specific Hypotheses

It is hypothesized that there is a difference in the total pharyngeal airway volume, the sagittal airway area, and the most constricted cross sectional area of the pharynx between skeletal Class I and II patients. Futhermore, it is hypothesized that there is a linear correlation between the ANB angle and the most constricted cross sectional area of the pharynx.

The null hypothesis is that there is no difference in the total pharyngeal airway volume, the sagittal airway area, and the most constricted cross sectional area of the pharynx between skeletal Class I and II patients. Furthermore, there is no linear correlation between the ANB angle and the most constricted cross sectional area of the pharynx.

III. MATERIALS AND METHODS

A. Experimental Design

For this retrospective study, 100 patients who received comprehensive orthodontic treatment between 2007 and 2013 at the Tri-Service Orthodontic Residency Program (TORP) at JBSA-San Antonio, Lackland AFB, Texas were randomly selected from the clinic records. As part of routine orthodontic records, these patients had received CBCT scans of their head before treatment. Patients who had soft tissue pathology detected in the scans or their medical history, previous Orthognathic surgery, or a syndrome diagnosis were excluded. Patients were healthy, non-growing patients over the age of 16 with Caucasian, Asian, Hispanic and African-American ethnicities represented.

The patients were divided into two groups according to their pre-treatment anteroposterior skeletal pattern as determined by ANB angle. A skeletal Class I group (Group I) was composed of the first 50 patients from the TORP patient database with ANB angles of 0° to 4° who met the inclusion criteria. A skeletal Class II group (Group II) was composed of the first 50 patients with ANB angles of greater than 6° who meet the inclusion criteria. A faculty member not associated with the study then approved all patients from the Tri Service Orthodontic Residency Program (TORP) archived patient database. Patients were de-identified, randomized and their CBCT's loaded into a research folder on Dolphin Imaging® software, version 11.5 (Dolphin Imaging, Chatsworth, California, USA). CBCT's were labeled only with a number 1-100. The skeletal

Classification for each CBCT was maintained in a separate table that was unavailable to the Principle Investigator (PI) during CBCT measurement.

Patients were scanned seated upright in natural head position with their teeth in maximum intercuspation and were instructed to breathe normally and to hold still during the scan. All scans were taken with the i-CAT™ Platinum Cone Beam Computed Tomography machine (Imaging Sciences International, Hatfield, PA, USA) according to the clinic protocol used for initial orthodontic records. Scans were obtained using one 360° rotation with 17 cm x 23 cm field of view, 0.3 mm voxel size and 17.8 sec scan time. All images were collected at 120 kVp and 5 mA based on the manufacturer's specifications. The scans provided a full field of view including the cranial base, the face, and the pharyngeal airway.

Data was imported to Dolphin Imaging® software in DICOM format. Dolphin Imaging® software generates a three-dimensional head rendering of the CBCT data which were oriented in three planes of space (Figure 1). The axial plane was constructed passing through right porion (most superior point of the external auditory meatus) and the right and left orbital points (most inferior point on the orbital rim). The coronal plane passes through right and left porion and is perpendicular to the axial plane. The sagittal plane passes through nasion (point where the frontal-nasal and inter-nasal sutures meet) and is perpendicular to the axial and coronal planes.

Using the oriented image, reconstructed 2D lateral cephalometric images were generated using the ray-sum technique, orthogonal projection type and a

100 mm ruler in the image. The lateral cephalograms were digitized by one examiner (DTE) and skeletal landmarks were identified (Figure 2). The Dolphin Software automatically calculates cephalometric angles and measurements from the cephalometric landmarks selected. Four anterior-posterior measurements (Sella-Nasion-A point {SNA}, Sella-Nasion-B Point {SNB}, A Point-Nasion-B Point {ANB}, Wits (calculated from functional occlusal plane bisecting the 1st bicuspids)) were recorded and 3 vertical measurements (Sella-Nasion-Mandibular Plane {SN-MP}, Frankfort-Mandibular Plane Angle {FMA}, Posterior Facial Height: Anterior Facial Height {PFH:AFH}) were recorded.

The Sinus/Airway tool in Dolphin Imaging software was used to measure the airway. The boundaries of the pharyngeal airway in the sagittal plane were defined as, anterior-inferior—the tip of the epiglottis, posterior-inferior—wall of the pharynx opposite the epiglottis on the plane parallel to Frankfort horizontal, anterior-superior—the posterior edge of the hard palate, posterior-superior—the wall of the pharynx opposite the hard palate on the plane parallel to FH plane. A single seed point was placed in the center of the defined airway space. On some patients, if the anterior boundary was drawn as a straight line, airway volume from the oral cavity would have been included. For these patients, the anterior boundary of the airway was traced though the soft palate down to the base of the tongue. All measurements were made at both slice airway threshold sensitivities 55 and 73 (T55 and T73) [23]. Dolphin software measures total airway volume (mm^3), sagittal airway area (mm^2) and MCA (mm^2) based on these parameters. Airway measurements were recorded for statistical analysis.

Figure 1

Orientation of 3D Skull renderings

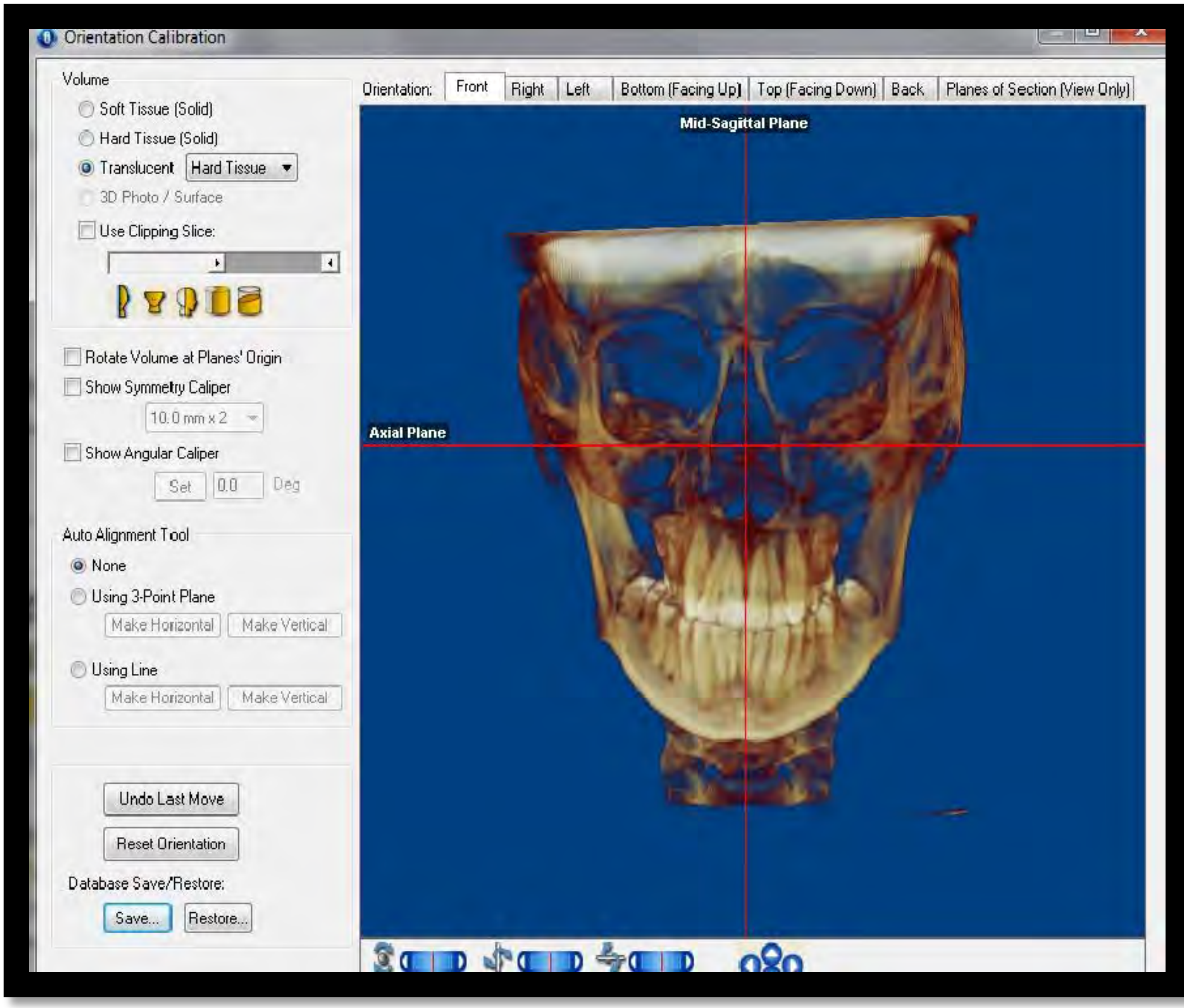


Figure 2

Traced Reconstructed Lateral Cephalogram

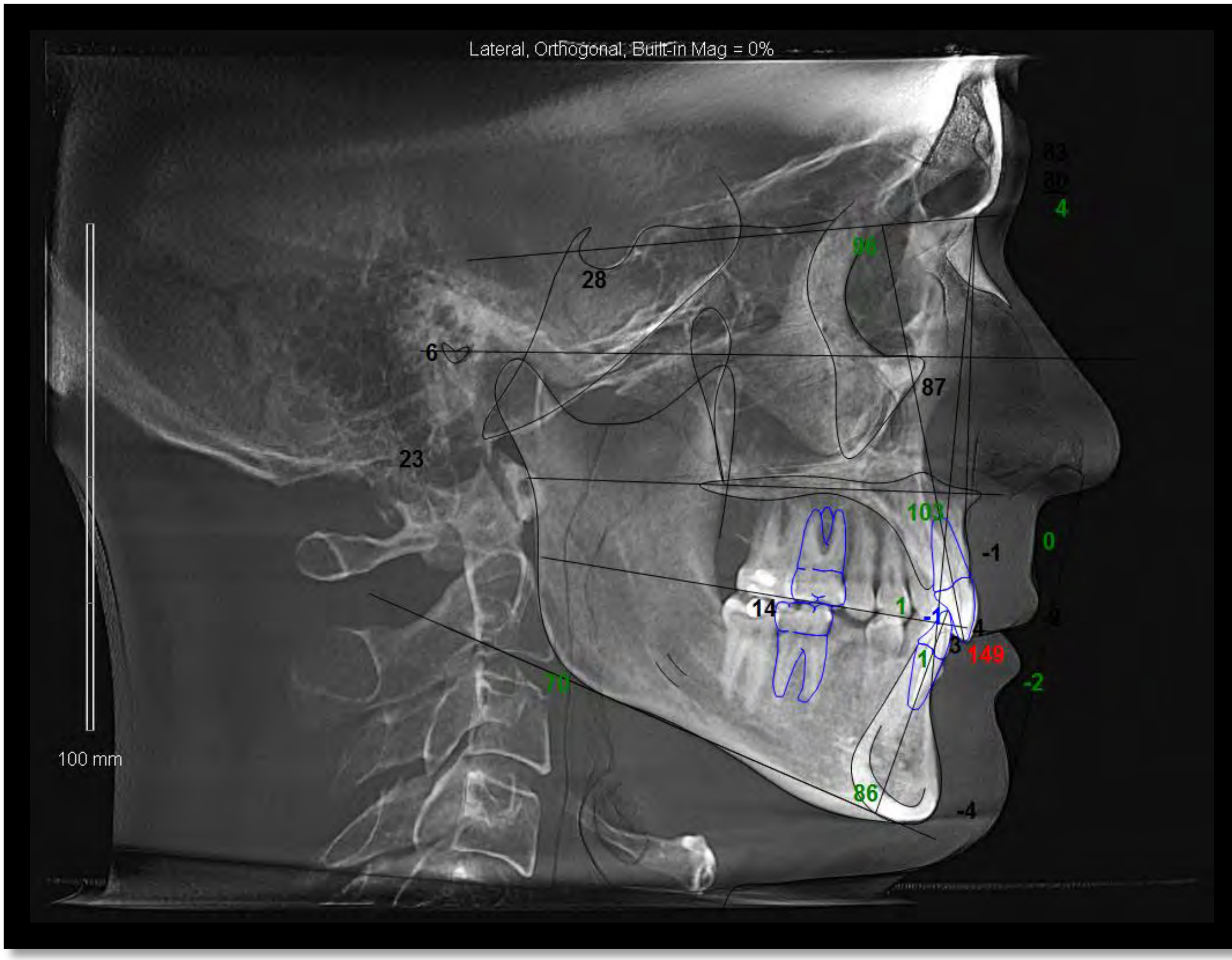


Figure 3

Effect of Threshold value on Airway Generation: T73

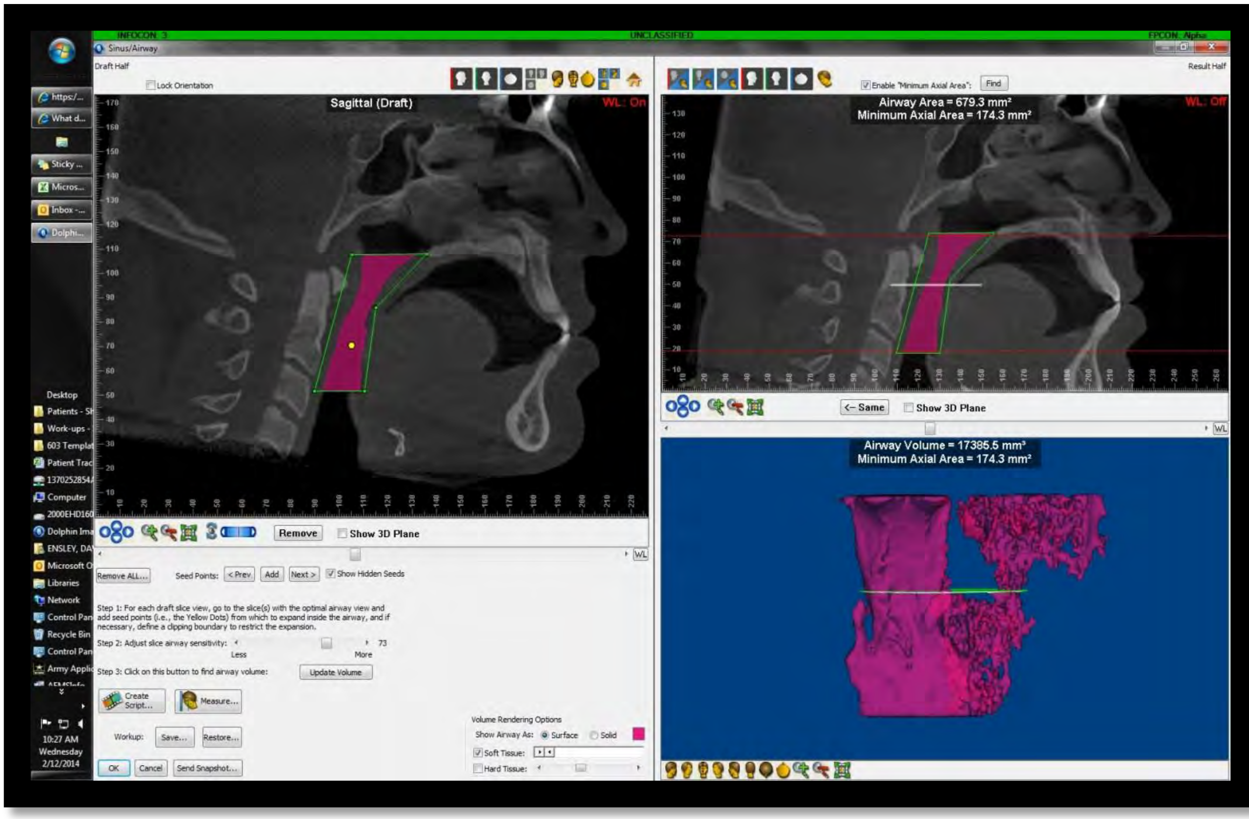


Figure 4

Effect of Threshold value on Airway Generation: T55

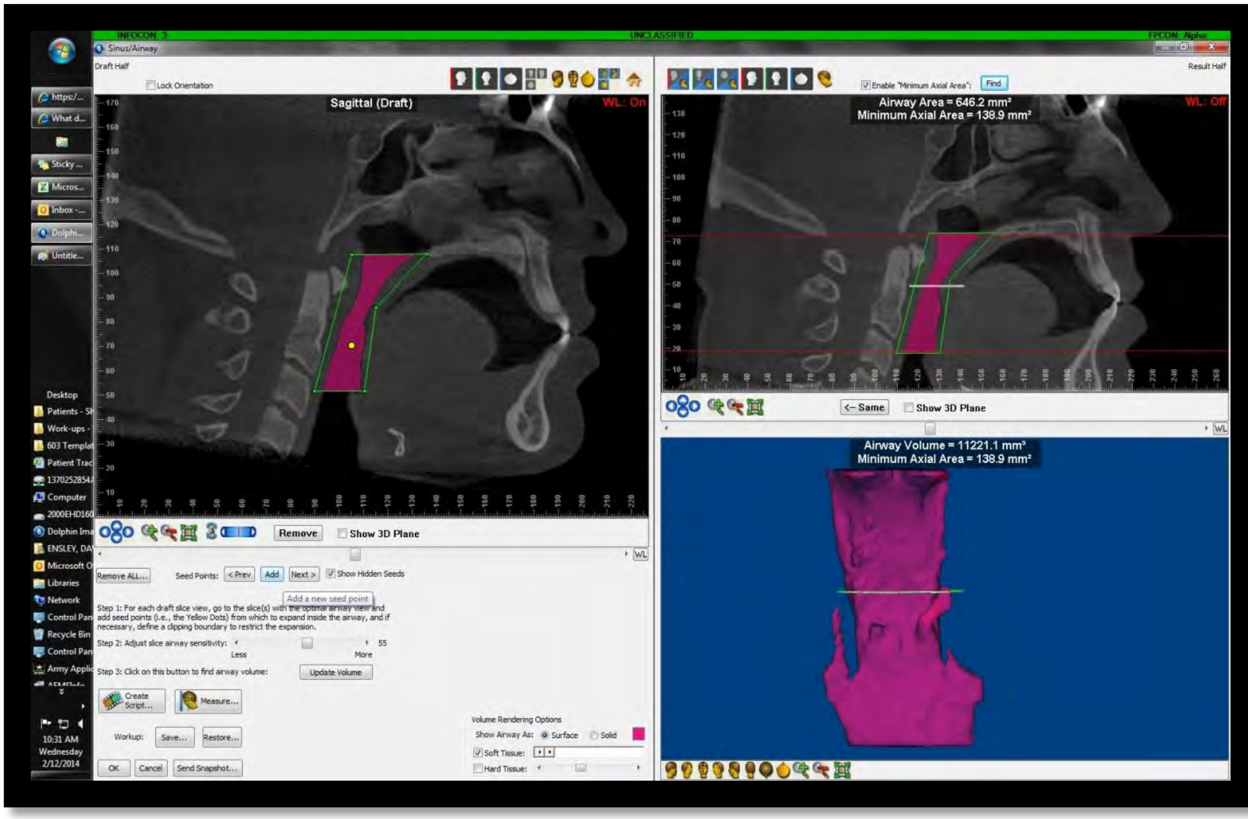


Figure 5

Effect of Incorrect Limits When Measuring Minimal Cross-sectional Area

Notice how the sagittal slice has cut through only a portion of the bottom of the airway, which is not an accurate representation of the MCA of the airway.

Figure 6

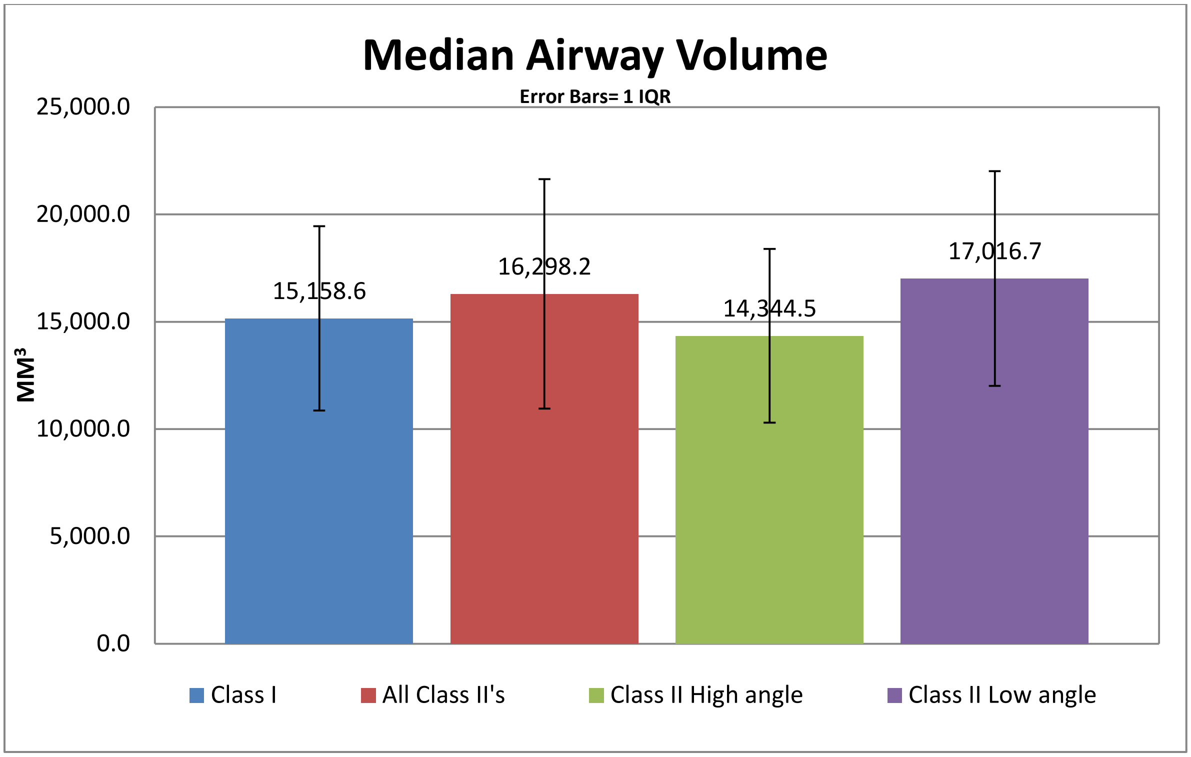


Figure 7

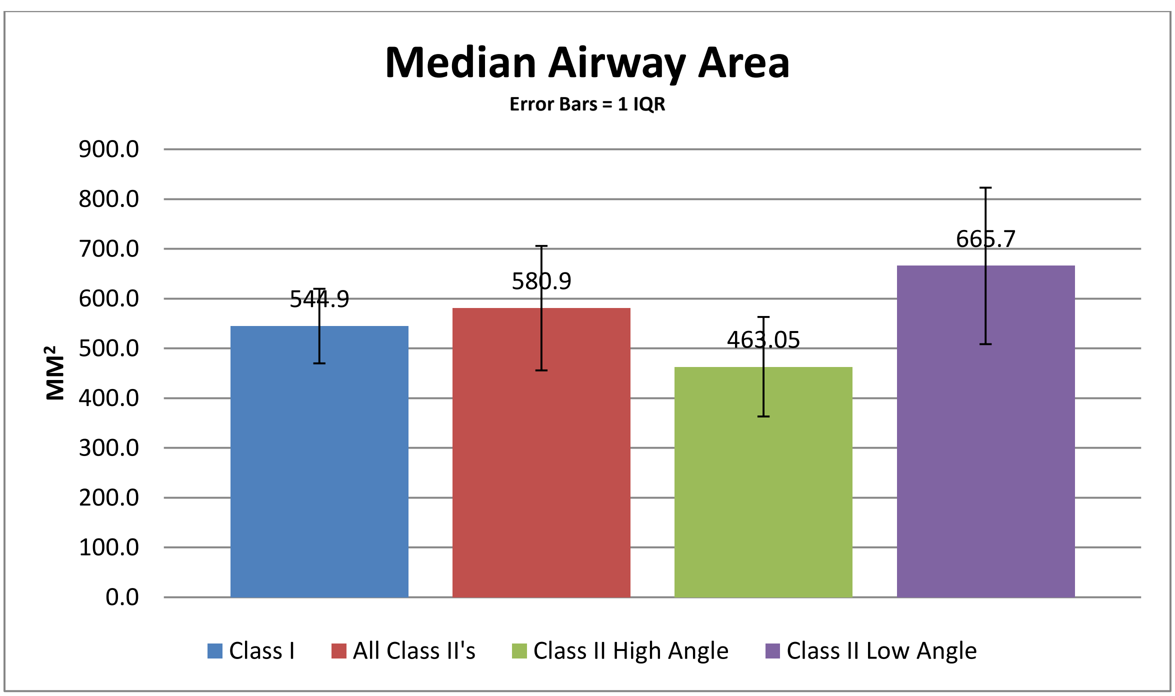
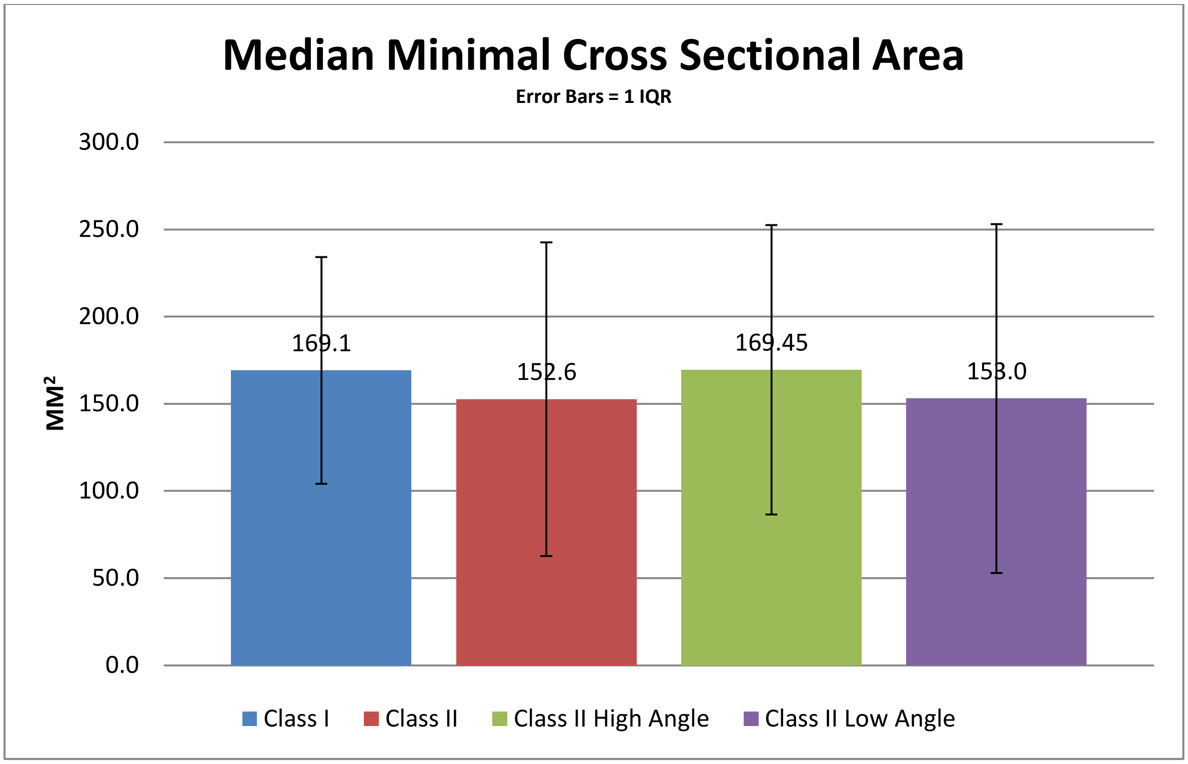


Figure 8



Median Minimal Cross Sectional Area
Error Bars = 1 IQR
MM²
300.0
250.0
200.0
150.0
100.0
50.0
0.0
169.1
152.6
169.45
153.0
Class I
Class II
Class II High Angle
Class II Low Angle

B. Statistical Management of Data

The reliability of measurements was tested by randomly selecting 10 subjects whose airway volumes were remeasured. A Pearson correlation test between the two measures showed each airway measurement to be highly correlated (Volume r=0.996, Sagittal Area r=0.996, MCA r=0.999). The high correlations between the two measurements are largely due to the automatic nature of the airway measurements made by Dolphin and the ease of identifying the boundary points for the airway.

Descriptive statistics were calculated for all variables measured. The two experimental groups were compared to ensure an even distribution of age and sex in both groups. A Shapiro-Wilk normality test showed that the distribution of ages was not normal. A Mann Whitney U test showed that there was no difference in the median ages of the two groups(p=0.054) A Pearson's Chi Squared test showed an even distribution of sexes in both experimental groups (p=0.109) A Shapiro-Wilk normality test demonstrated that all cephalometric values except for SNA and ANB were normally distributed. All airway measurements were not normally distributed. A Mann Whitney U test was used to compare the statistical difference between the experimental groups for airway volume, sagittal area and MCA. The Class II experimental group was further subdivided into low (FMA<20) and high angle (FMA>30) groups. Mann Whitney U test was used to compare these subgroups to the Class I group. Groups were also subdivided based on age and compared with a Mann Whitney U test. Class I patients 25 year old and younger were compared to Class II patients 25 years old and younger. Class I ages 26-40 were compared to Class II patients age 26-40. Pearson correlations were used to determine the linear correlation between Wits' measure and MCA as well as ANB and MCA. The linear correlation between airway volume, sagittal area and MCA was determined by Spearman correlation.

IV. RESULTS

The median average volume of the pharyngeal airway was 15.5 cm^3 (IQR 7.3 cm^3) when measured at T73. There was no statistical difference between the airway volume, sagittal area or MCA between the skeletal Class I group and the skeletal Class II group ($p = 0.823$, 0.964, 0.669 respectively). The median averages at T73 for Class I patients were 15.2 cm^3, 544 mm^2, and 199 mm^2 respectively for airway volume, sagittal area and MCA. For Class II patients at T73, the median averages were 16.3 cm^3, 580.9 mm^2, and 188.4 mm^2 for airway volume, sagittal area and MCA respectively. There was a large variation in airway sizes demonstrated by the coefficient of variation for volume, sagittal area and MCA 41.9%, 29.2% and 55.6% respectively.

Results generated at T55 were similar to those at T73, only with smaller measurements. The median volume was 11.5 cm^3 (IQR 7.2 cm^3) when measured at T55. There was no statistical difference between the airway volume, sagittal area or MCA between the skeletal Class I group and the skeletal Class II group. The median averages at T55 for Class I patients were 11.4 cm^3, 500.1 mm^2, and 169.1mm^2 respectively for airway volume, sagittal area and MCA. For Class II patients at T55, the median averages were 12.5 cm^3, 570.3 mm^2 and 152.6mm^2 for airway volume, sagittal area and MCA respectively.

When the Class II group was further subdivided into high and low angle Class II, there was a significant difference in the median sagittal airway areas between skeletal Class II patients with an FMA>30° (544.9 mm^2) and the Class I group median of 463.0 mm^2 (p=0.045) at T73. There were no other significant differences between either low or high angle Class II patients and the Class I group. Airway measurements for the low angle Class II patients were 17.0 cm^3, 665.7 mm^2, and 153.0 mm^2 respectively for volume, sagittal area and MCA at T73. Measurements for the high angle Class II patients were 14.3 cm^3, 463.05 mm^2, and 169.45 mm^2 at T73.

The experimental groups were subdivided based on age. Young Class I patients (age 25 and younger) were compared to young Class II patients. Class II patients, age 25-40, were compared to Class I patients, age 25-40. At T55, there were no significant differences in airway volume, sagittal area or MCA in either of these comparisons (Table 3). Median average volume, sagittal area and MCA for the young Class I sample were 11.4 cm^3, 500.1 mm^2, 156.2 mm^2 respectively. For the young Class II sample they were 12.6 cm^3, 570.3 mm^2, and 150.2 mm^2. The sample aged 26-40 measured 11.3 cm^3, 497.9 mm^2, and 180.1 mm^2 respectively for the volume, sagittal area and MCA of Class I patients. The Class II group measured 12.1 cm^3, 567.3 mm^2, and 161.5 mm^2.

Linear correlations comparing Wits and MCA were used at T73 and T55. Neither showed significant correlation (r=0.107 and r=0.106 respectively). Spearman correlations also did not show a relationship between ANB and MCA (T73 and T55) (r=0.053 and r=0.033). Spearman correlations were also used to evaluate the relationship between airway volume, sagittal area and MCA among Class I and Class II patients at T55. All three measures were highly correlated, but the highest correlation was between airway volume and MCA in skeletal Class I patients (r=0.885). The correlation values are found in Table 4.

TABLE 1: Descriptive Statistics for Cephalometric Values and Airway Measurements.

Variable		Group I		Group II	
		Mean	**SD**	**Mean**	**SD**
Age (yrs)		25	7	27	7
ANB (°)		2.41	1.01	7.49	1.35
SNA (°)		82.8	3.1	83.9	4.6
SNB (°)		80.4	3.2	76.4	4.3
Wits (mm)		-1.0	2.3	4.8	3.0
PFH:AFH (%)		64.1	5.8	65.7	7.4
FMA (°)		27.2	6.2	27.0	7.6
SN:MP (°)		36.0	7.0	35.4	9.1
		Median	**IQR**	**Median**	**IQR**
Airway Volume (T73) mm^3		15,158.6	8,608.9	16,298.2	10,691.2
Airway Area (T73) mm^2		544.9	149.5	580.9	256.6
Airway MCA (T73) mm^2		199.4	132.9	188.4	180.2
Airway Volume (T55) mm^3		11,405.3	7,187.2	12,507.9	6,986.9
Airway Area (T55) mm^2		500.1	160.1	570.3	277.5
Airway MCA (T55) mm^2		169.1	138.1	152.6	162.4

TABLE 2: Airway Measurements for Low/High Angle Patients

Values listed with * are statistically significant**

T73	**Volume (mm^3)**	**Sagittal Area (mm^2)**	**MCA (mm^2)**
Low Angle Class II (n=9)	17,016.7	665.7	153.0
High Angle Class II (n=20)	14,344.5	463.05***	169.45
Class I	15,158.6	544.9***	199.4
T55			
Low Angle Class II (n=9)	12,965.8	626.2	136.4
High Angle Class II (n=20)	11,214.0	432.8	122.3
Class I	11,405.3	500.1	169.1

TABLE 3: Airway measurements for Different Age Groups

T55	**Volume (mm^3)**	**Sagittal Area (mm^2)**	**MCA (mm^2)**
Class I 16-25 yrs (n=28)	11,409.5	500.1	156.2
Class II 16-25 yrs (n=22)	12,638.4	570.3	150.2
Class I 26-40 yrs (n=22)	11,334.9	497.9	180.1
Class II 26-40 yrs (n=28)	12,107.0	567.3	161.5

TABLE 4: Spearman Correlations

Spearman Correlations	MCA (T73)	MCA (T55)
ANB	0.053	0.033
WITS	0.107	0.106

T55/Group I	Volume	Area	MCA
Volume	1	0.816	0.885
Area	0.816	1	0.694

T55/Group II	Volume	Area	MCA
Volume	1	0.854	0.854
Area	0.854	1	0.86

V. DISCUSSION

The main objective of this study was to assess the volume, sagittal area and MCA of the pharyngeal airway in Class I and Class II (divided based on ANB angle) adult patients using CBCT. The study utilized Dolphin Imaging software, which is commonly used in orthodontic practice. Dolphin Imaging software has also been utilized in many recent CBCT based airway studies.

When using the Dolphin airway tool, a threshold sensitivity value must be specified that adjusts what densities the software considers soft tissue and what is considered airway. The study was initially conducted using T73, which was recommended by Alves[23]. Alves generated resin prototypes of CBCT airway volumes. He then scanned the resin prototype and measured its volume at different threshold levels. T73 gave the closest volume to the actual measured volume of the resin airway prototype. However, when the current study was conducted, T73 did not give satisfactory results. When viewed graphically the airways generated at this threshold consistently showed extensions and roughness in areas that should have been soft tissue, not airway. A typical airway generated at this threshold is illustrated in Figure 3.

Ye et al[25], in a response to Alves' article, stated two objections to the methods used in the study. First, the density of the resin prototype would be different than that of soft tissue. Secondly, the tube voltage on different CBCT machines varies which leads to different computed tomography values of the same tissue. Thus, different threshold values would need to be used for different CBCT machines.

Given the problems with T73, all airways were re-measured at T55 which was the highest threshold value that gave smooth, defined contours to the graphically generated airway model. The values generated at T55 were smaller, but usually proportionate to those generated at T73. A representative airway at T55 is shown in Figure 4. Note the smooth continuous airway outline.

The threshold value is only one variable affecting the measurements generated by Dolphin. The quality of the CBCT scan is critically important. The scan parameters and the voxel size will determine the resolution of the CBCT. Obviously, Dolphin will give two different measurements for the exact same airway if one was scanned at 0.3 mm voxels and the other at 2.0 mm voxels due to the irregularity of the airway boundary on the 2.0 mm voxel scan. The irregularity of the airway boundary has a greater effect on the measurements when measuring the nasal cavity and sinuses where there is a large surface area of airway boundaries compared to the pharyngeal area measured in this study. This study addressed the influence the CBCT scans have on the Dolphin measurements by having all scans done on the same machine with the same scan parameters.

The results of this study support the null hypothesis that there is no difference in airway volume, sagittal area, or MCA between adult, non-growing patients with normal anteroposterior skeletal patterns and those with a Class II anteroposterior discrepancy. The result was the same at Threshold T73 and T55. Additionally, the linear correlations used between ANB and MCA, and Wits and MCA did not show any significant correlation. While not significant, the mean and the median airway volume were actually larger in Class II patients.

The results of this study agree with the findings of Alves[9], which showed no difference in the airways between Class II and Class III malocclusions. Similar to the current study, Alves noted that the difference in ANB between the two adult experimental groups was due to differences in SNB, not SNA.

However, several recent studies conducted using CBCT have shown a significant difference between Class I, II and III patients. Claudinoa et al divided the airway into four sections, the nasopharynx, oropharynx, velopharynx and hypopharynx[12]. The nasopharynx and hypopharnx areas included in Claudinoa's research were not evaluated in the current study. Claudinoa also included Class III patients in the study. Unlike the current study, they found significant differences in the minimal axial area and mean area of the velopharynx between Class I and II. Results that were similar to the current study are that they did not find a difference between minimal or mean areas between Class I and II's in the oropharynx or in the total lower pharyngeal portion. Also, they recorded large variations in the sizes of the airways with large standard deviations.

Another study utilizing CBCT that showed a difference in airways was by Alves[27]. This is a separate study from the Alves study mentioned previously. They segmented the pharyngeal airway using Dolphin imaging using the same parameters as the current study. However, this study was conducted using a homogenous sample of Caucasian, Brazilian children ages 8-10. They were able to show a statistically significant difference in airway volume, sagittal area and

MCA between Class I and II's. Variations in the sizes of airways, based on standard deviation were lower for Alves than the current study. Perhaps, the diversity in ethnicity and age in the current study produced such variation in other influences of airway size such as soft palate length, parapharyngeal fat pad size[20], and tongue size and posture that a possible influence of skeletal anteroposterior profile was obscured.

Consider two very different patients who could have the same ANB angle indicating a Class II malocclusion: Would a bimaxillary dentoalveolar protrusive African-American patient with an ANB of 8 have a similar airway to a petite, Caucasian female with an ANB of 8? In Class I patients, would an overweight, low angle male with an ANB of 2 have the same airway size as a high angle, normal weight patient with an ANB of 2? These questions highlight the idea that there is more to airway size than just AP considerations.

Much of the current interest in airway research has been elicited by the increasing prevalence of obstructive sleep apnea. A better understanding and awareness of the factors governing airway size and morphology will clearly assist in preventing and treating OSA. However, the current study was conducted on alert, upright patients. Eung-Kwong et al showed a decrease in oropharyngeal cross sectional area of 28.8-36.5% measured cephalometrically in patients when moving from the upright to supine position[21]. Additionally, Ingman et al reported narrowing of the oropharyngeal space in patients with sleep apnea when comparing cephalograms of upright versus supine patients[22]. Even something as minor as whether the patient's mouth was open or closed affects the size of the airway[26]. These studies call into question the usefulness of upright airway data unless the decrease in airway is consistent and predictable.

VI. CONCLUSIONS

1. There is no difference in the total volume, sagittal area or minimal cross sectional area of the pharyngeal airway between skeletal Class I and Class II patients.

2. The sagittal airway area is significantly smaller in high angle (FMA greater than 30°) Class II patients than in Class I patients.

3. Dolphin Imaging software provides a highly reliable and reproducible method of measuring pharyngeal airways on CBCT images.

4. Airway volume, sagittal area and minimal cross sectional area are highly linearly correlated.

5. There is a high degree of variability in the size of patient airways.

Appendix A-Raw Data (7 Cephalometic Landmarks n=100)

CBCT #	Group	SNA (°)	SNB (°)	ANB (°)	Wits (mm)	PFH:AFH	FMA (°)	SN-MP (°)
1	1	80.5	80.1	0.4	-2.7	59.0	29.3	36.9
3	1	87.2	84.7	2.4	-3.4	72.4	17.9	26.5
5	1	80.1	77.4	2.7	-0.5	69.6	18.4	27.2
6	1	78.9	75.9	3.1	-2.9	63.5	23.3	36.2
9	1	81.8	79.1	2.7	1.3	61.9	26.4	35.1
10	1	86.7	83.2	3.5	-6.8	58.8	27	41.6
14	1	88.4	85.8	2.6	1.3	68.4	22.7	29.5
16	1	85.6	83.4	2.2	-1.5	67.8	25.7	34.4
18	1	84.0	81.2	2.8	-2.8	71.6	24	31.7
20	1	85.3	81.2	4.0	-0.2	58.0	32.4	40.4
21	1	82.6	80.3	2.3	-2.0	62.7	23.7	35
23	1	79.9	77.9	1.9	-1.6	53.5	33.9	51.2
24	1	82.0	78.9	3.1	1.6	69.5	22.6	27.2
27	1	83.3	79.8	3.5	0.9	75.2	18.6	21.8
28	1	80.0	78.4	1.6	1.4	65.4	24.4	34
31	1	83.8	82.0	1.8	-0.3	60.2	30.7	38.3
33	1	82.7	79.1	3.6	0.8	69.1	24	32.7
34	1	79.4	76.2	3.2	-0.2	67.0	21.2	29.1
35	1	78.2	77.9	0.3	-0.3	59.9	41.3	46.5
41	1	80.1	77.4	2.7	-4.3	67.0	26.7	36.7
42	1	83.8	82.2	1.6	-1.2	57.9	33.1	42
45	1	78.7	75.3	3.3	0.6	68.5	23.2	29.2
46	1	83.0	79.9	3.1	2.4	63.7	25.4	33
47	1	82.7	79.4	3.3	-0.9	57.4	29.6	40.4
48	1	78.1	76.7	1.4	-5.0	60.6	32	43.1
49	1	83.2	80.1	3.1	-2.0	55.2	24.3	34.5
50	1	81.0	77.9	3.1	-3.7	73.2	22.8	28.3
52	1	83.5	80.9	2.6	0.2	63.2	29.1	37.8
53	1	83.0	81.1	1.9	-3.0	59.6	39.8	44.8
56	1	83.8	82.2	1.7	-2.3	58.3	28.1	40.9
57	1	85.3	82.9	2.4	3.0	64.5	24.7	34
60	1	80.5	77.3	3.2	-0.2	71.1	17.4	24.1

CBCT #	Group	SNA (°)	SNB (°)	ANB (°)	Wits (mm)	PFH:AFH	FMA (°)	SN-MP (°)
64	1	84.7	80.3	4.0	-1.0	72.6	16.6	26.9
65	1	81.4	78.6	2.7	3.0	63.7	28.7	39.4
66	1	82.1	78.2	3.9	1.6	64.5	28.2	37.5
68	1	83.2	82.2	1.0	-1.9	53.4	40.5	51.8
69	1	84.9	82.7	2.2	-2.7	67.9	24.6	33.4
71	1	77.0	76.2	0.8	-2.1	64.7	28.8	38.1
74	1	78.6	77.0	1.6	0.7	67.3	28.8	34.5
76	1	87.1	83.0	4.0	-2.1	53.3	46.5	53.0
77	1	77.0	75.0	2.0	-2.8	62.4	31.6	43.3
79	1	84.2	83.7	0.5	-2.4	58.0	32.5	39.2
82	1	84.6	83.5	1.2	1.1	73.0	23.5	27.5
84	1	88.1	86.6	1.5	-4.5	64.9	28.6	33.1
85	1	84.7	82.1	2.6	-0.3	68.6	25.9	32.0
90	1	91.4	88.9	2.5	2.5	73.7	21.8	27.9
92	1	79.1	74.8	4.0	1.1	65.3	25.0	34.8
93	1	85.3	82.6	2.7	-3.6	60.7	22.9	38.3
97	1	86.8	85.4	1.4	2.4	61.4	29.7	39.2
100	1	82.7	82.0	0.6	-4.8	57.8	31.5	44
Mean		82.8	80.4	2.4	-1.0	64.1	27.2	36.0
St Dev		3.1	3.2	1.0	2.3	5.8	6.2	7.0
Median		83	80.2	2.6	-1	64.1	26.2	35.1
2	2	88.7	81.7	7	5.8	68.1	24.9	29.1
4	2	81	73.5	7.4	7.3	72.1	20.4	27.2
7	2	84.6	77.3	7.3	7.3	66.3	28.3	35.8
8	2	86.6	79.8	6.8	5.4	59.3	40.7	46.7
11	2	88.3	81.7	6.5	2.8	67.8	30.7	35.6
12	2	81.4	74.1	8.9	3.7	65.3	19.6	31.4
13	2	87	79.1	8	4.6	67.8	23.5	31.0
15	2	79.9	72.9	7.1	6	74	21.8	29.9
17	2	82.8	76.4	6.5	4.3	67.3	30.2	37.2
19	2	85.1	77.5	7.7	1.3	62.2	27.1	39.3
22	2	81.2	74.3	6.9	4.5	56.3	32.3	43.1
25	2	84.7	78.4	6.2	2.3	75.2	14.3	22.9

CBCT #	Group	SNA (°)	SNB (°)	ANB (°)	Wits (mm)	PFH:AFH	FMA (°)	SN-MP (°)
26	2	83.5	76.7	6.9	3.4	69.8	24.2	30.5
29	2	77.0	70.8	6.2	3.5	64.7	22.8	34.7
30	2	81.7	72.6	9.0	11.5	62.3	25.1	34.4
32	2	84.2	78.6	5.6	9.0	65.0	24.9	35.3
36	2	81.3	73.2	8.1	5.8	58.8	34.1	44.7
37	2	85.9	78.1	7.9	6.0	75.2	27.0	30.0
38	2	82.5	76.1	6.4	5.1	69.8	24.3	31.2
39	2	84.9	78.6	6.2	3.7	69.3	31.9	39.0
40	2	82.4	75.0	7.4	0.6	64.6	19.1	31.8
43	2	89.1	82.1	7.0	1.3	55.4	34.5	49.5
44	2	94.7	84.7	10.1	4.4	51.1	37.5	51.4
51	2	95.0	86.5	8.5	2.3	65.8	21.2	33.6
54	2	85.2	74.2	11.0	3.7	71.9	21.4	27.9
55	2	84.2	77.8	6.4	4.7	67.0	22.4	29.4
58	2	87.6	80.9	6.6	1.2	65.4	23.5	37.9
59	2	81.1	74.2	6.9	4.7	63.1	35.4	41.6
61	2	87.1	76.7	10.3	5.5	72.8	22.9	26.8
62	2	86.7	78.6	8.1	6.6	52.7	35.6	47.3
63	2	78.1	70	8.0	12.3	78.0	9.8	19.5
67	2	82.0	71.6	10.4	7.2	72.6	21.8	26.6
70	2	82.5	76.2	6.3	4.7	59.3	31.2	37.0
72	2	75.7	69.6	6.1	-0.2	72.3	18.0	25.9
73	2	78.8	72.4	6.4	3.3	65.8	27.3	32.5
75	2	84.1	77.4	6.7	7.9	57.5	35.4	50.0
78	2	81.0	74.0	7.0	3.6	61.2	28.0	38.5
80	2	79.9	71.7	8.2	4.8	58.0	37.3	47.9
81	2	84.5	77.8	6.7	6.8	52.7	33.6	46.1
83	2	78.2	71.4	6.8	3.3	81.3	13.2	14.3
86	2	80.6	74.2	6.3	-1.7	51.2	44.6	55.0
87	2	78.1	70.8	7.3	10.3	59.0	33.1	46.2
88	2	80.8	70.7	10.1	7.8	59.6	33.1	39.5
89	2	78.4	72.1	6.3	9.0	76.2	16.4	23.7
91	2	80.6	74.0	6.6	-1.3	62.4	35.2	43.6
94	2	94.7	86.1	8.6	2.0	61.5	33.2	41.7
95	2	90.6	80.2	10.4	3.2	80.8	14.9	18.0

CBCT #	Group	SNA (°)	SNB (°)	ANB (°)	Wits (mm)	PFH:AFH	FMA (°)	SN-MP (°)
96	2	82.7	76.2	6.5	2.0	67.8	30.0	31.5
98	2	93.5	87.3	6.2	6.7	65.4	32.0	38.5
99	2	85.0	76.4	8.6	8.5	73.8	18.1	28.6
Mean		83.9	76.4	7.5	4.8	65.7	27	35.4
St Dev		4.6	4.3	1.3	3	7.4	7.6	9.1
Median		83.15	76.3	7	4.65	65.6	27.05	35

Appendix B: Raw Data (Two Thresholds, three measurements n=100)

	T73			T55		
CBCT #	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)
Group 1						
1	18655.3	476.3	319.7	11419.3	404	267.2
3	12048.4	486.1	132.4	8714.4	411.5	110.9
5	30741.6	905.1	566.8	24957.8	820.6	496
6	27056.6	905.2	289.2	19154	877.6	270.2
9	14204.5	548.1	211.1	9598.4	523.7	158.6
10	11940.9	495.5	153.4	9570.3	465.8	141.8
14	12801.4	526.3	195.5	10537.5	494.5	170.3
16	15626.8	464.6	206.5	14157.2	458.7	185.8
18	9345.9	502.1	103.7	7524.8	423.2	84.5
20	12791.3	554.1	249.8	10328	500	194.3
21	14929	590.8	230.2	11783.9	524.6	185.1
23	6672.7	383.9	75.9	5870.3	374.8	63.5
24	15137.8	541.6	100.3	11008	480.9	87.2
27	26024.3	929.5	355.3	20572.7	883.7	313.8
28	19394.2	703.3	196.8	15156.3	640.9	143.2
31	24352.4	592.9	438.9	16513.6	557.6	264.7
33	10705.4	470.9	88.5	7899.9	438.5	77.8
34	7732.7	557.3	83.3	6841.5	531	69
35	18213.7	649.1	165.8	14107.8	619.2	150.2

	T73			T55		
CBCT #	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)
41	12168.2	478	159.5	7566.1	463.8	119
42	21826.2	658.1	282.8	17578.5	621.5	259.3
45	14109.8	486.5	150.5	10459.1	501.2	131.3
46	21238.9	600.4	339	16837.5	582.9	318.4
47	9732.3	333.8	52.8	4845	325	43.1
48	22024.7	797.4	273.2	17061.4	764.7	225.8
49	11686.6	377.3	200.2	9606.4	377.5	175
50	10706.2	517.9	91	8753.6	487.3	78.1
52	16404.6	518.4	208.3	11399.7	493.4	167.9
53	39872.7	1098.1	463	30872.3	1072.6	431
56	13031.6	517.5	110.7	10609.2	491.2	92.8
57	13357.5	561.4	149	8033.1	500.2	104
60	14030.3	433.9	176	9183.6	389.8	148
64	13424.5	456.5	187.4	10966.4	428.9	144.6
65	24583.1	799.2	397.3	21136.6	776.7	359.3
66	26710.1	725.4	424.3	21652.7	714.9	320
68	13894.1	439.7	152.8	11258.9	415.7	136.8
69	23677.1	645.9	346.6	17920.2	621.6	308.5
71	11716.9	487.5	137.4	9403.9	466.3	117.7
74	18847.3	636.6	180.1	15832.4	609.5	162.1
76	8974.4	442.8	62.8	6697.5	405.9	46

	T73			T55		
CBCT #	**Total Volume (mm^3)**	**Airway Area (mm^2)**	**MCA (mm^2)**	**Total Volume (mm^3)**	**Airway Area (mm^2)**	**MCA (mm^2)**
77	16192.8	567.2	225.1	13466.1	544	197.2
79	29600.5	891.2	204.8	24840.2	867.9	191
82	21459.8	608.3	329.2	16735.5	586.2	275.9
84	21457.3	552.2	371.2	16672.4	521.9	272.5
85	15179.4	404.5	132.5	11209.8	381.6	119.2
90	13021	462.4	183.4	9075	434.1	139.9
92	20179	602.9	280.8	15244.6	576.9	250.7
93	15434.9	515.5	198.5	13024.4	499	185
97	14384.7	523.8	272.9	11410.9	492	227.7
100	15223.3	579.5	209.5	11509.8	567.2	191.1
Group 2						
2	23669.7	670.9	415.1	14780.8	692.8	284.9
4	22286.2	671	396.3	18390.1	646.1	365.5
7	41313.5	1106.7	353.2	32753	1111.7	294.5
8	10577.3	350	80.9	8255	351.4	67.9
11	15163.6	334.6	121.6	12704.7	307.5	104.9
12	8303.7	414.6	70.1	7298.4	392.6	61
13	16824.4	723.3	223.6	14239.4	689.9	181.8
15	19444.3	633.7	276.4	15661.7	608.9	253.2
17	24378.9	639.7	285.9	17492.5	579.8	229.5
19	36246.4	935.5	443.2	29920.7	914.5	407

	T73			T55		
CBCT #	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)
22	7169.2	416.3	127	5484.5	392.8	91.9
25	28567.9	775.9	328.5	23838.1	750.6	300
26	10059.9	359.5	78.6	5109.2	332.6	56.6
29	13216.9	643.5	135.6	10180	617.5	115
30	17505.1	671.2	268.3	14953.3	645.7	221.8
32	16164.8	529.7	188.1	13883.4	470.4	173.4
36	10047	476.9	64.1	7964.6	451.3	54.2
37	17385.5	309.4	174.3	11221.1	646.2	138.9
38	20614.3	816.8	188.1	14452.7	775.2	154.8
39	14437.1	585.7	81.7	11509.3	553.4	72.6
40	10367.8	389.3	119.9	7949.4	369.3	103.4
43	11246.9	641.4	60.8	9931.2	601.5	49.8
44	15529.5	439.6	261.3	9146.6	341.7	102.3
51	35284.3	949.5	505.7	27333.6	913.9	363.7
54	22259.7	696.7	245.1	16368.2	691.1	215.8
55	16950.6	620.8	305.2	13103.3	591.4	272
58	10269.1	431.2	114.4	7886.9	172.3	79.3
59	22281.3	716.7	190.6	16888.4	691.2	172.5
61	11833.9	568.2	146.2	9993.5	531.5	125.1
62	24186.7	754.7	310.9	19865.6	713.2	304.5
63	13348.5	665.7	75.1	10877.9	626.2	62

	T73			T55		
CBCT #	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)	Total Volume (mm^3)	Airway Area (mm^2)	MCA (mm^2)
67	18316.6	683.2	299.8	14045.8	680.8	256.5
70	9243.2	375.7	114.9	7653.5	350.2	97.3
72	17016.7	570.6	153	12965.8	548.5	136.4
73	12893.5	483.7	206.5	9119.3	431.4	145.5
75	7367.1	438.7	94.2	6435.6	414.9	80.2
78	11501.6	344.8	186.4	9917.6	321.5	142.7
80	14251.9	477.9	70.3	10948.3	421.4	59.8
81	14003.7	227.2	183.8	9379	424.8	150.4
83	5595.4	425	67.1	4860.4	403.8	56.4
86	17205.2	438.7	188.6	12311	408.5	174
87	22411.2	724.5	256	19283.3	702.5	240.2
88	16431.6	612.6	280.3	13223.2	581.1	252.2
89	29561.5	812.2	475.9	22378.1	790.1	400.9
91	10339.7	430.8	155.1	8119.6	408.2	139.6
94	14172.1	449.2	228.6	11479.6	440.8	190.3
95	28758.5	739.7	592.5	22617.3	706.1	464.7
96	19760	576	84.2	11585.3	560.8	68.7
98	15542	488.7	306.7	13743.3	467.8	268.5
99	29754.8	691.8	508.5	25930.1	675.7	469.7

Appendix C: Raw Data (Age and Sex Data)

Group	CBCT Number	Age	Sex
1	1	17	M
1	3	17	F
1	5	27	F
1	6	16	F
1	9	36	M
1	10	26	F
1	14	28	M
1	16	26	F
1	18	17	F
1	20	20	F
1	21	37	F
1	23	35	F
1	24	21	F
1	27	35	M
1	28	25	M
1	31	25	M
1	33	26	F
1	34	17	F
1	35	22	M
1	41	19	F
1	42	36	M

Group	CBCT Number	Age	Sex
1	45	39	M
1	46	21	M
1	47	16	M
1	48	21	F
1	49	29	F
1	50	24	F
1	52	21	F
1	53	30	M
1	56	38	F
1	57	16	M
1	60	28	M
1	64	31	M
1	65	17	F
1	66	22	F
1	68	29	M
1	69	38	M
1	71	21	F
1	74	22	M
1	76	16	F
1	77	29	M
1	79	27	M
1	82	28	F

Group	CBCT Number	Age	Sex
1	84	17	M
1	85	18	F
1	90	22	F
1	92	23	F
1	93	22	F
1	97	36	M
1	100	16	M
Group 2			
2	2	25	M
2	4	28	M
2	7	32	M
2	8	17	M
2	11	38	F
2	12	27	M
2	13	23	F
2	15	24	M
2	17	22	F
2	19	22	M
2	22	17	M
2	25	35	F
2	26	17	M
2	29	23	M

Group	CBCT Number	Age	Sex
2	30	32	M
2	32	28	F
2	36	33	F
2	37	35	M
2	38	23	F
2	39	34	M
2	40	18	M
2	43	28	M
2	44	28	F
2	51	16	M
2	54	18	M
2	55	33	M
2	58	16	F
2	59	35	M
2	61	25	F
2	62	40	M
2	63	35	M
2	67	32	M
2	70	27	M
2	72	20	F
2	73	16	M
2	75	37	F

Group	CBCT Number	Age	Sex
2	78	25	M
2	80	31	M
2	81	31	M
2	83	39	F
2	86	17	F
2	87	22	F
2	88	32	M
2	89	19	F
2	91	29	F
2	94	36	M
2	95	30	F
2	96	16	F
2	98	34	M
2	99	35	M

Intra-Rater Reliability Raw Data

1st and 2nd Measurements of 10 Randomly Selected CBCT's

CBCT #	**6**	**33**	**65**	**74**	**93**
T73 Vol1 (mm^3)	27056.6	10705.4	24583.1	18847.3	15434.9
T73 Vol2 (mm^3)	27596.1	9911.6	25020.8	18718.4	15159.7
T73 Area1 (mm^2)	905.2	470.9	799.2	636.6	515.5
T73 Area2 (mm^2)	922.0	458.7	825.2	633.2	514.0
T73 MCA1 (mm^2)	289.2	88.5	397.3	180.1	198.5
T73 MCA2 (mm^2)	289.2	88.5	397.5	175.7	198.5
T55 Vol1 (mm^3)	19154.0	7899.9	21136.6	15832.4	13024.4
T55 Vol2 (mm^3)	19430.7	7750.9	21450.1	15750.0	12828.2
T55 Area1 (mm^2)	877.6	438.5	776.7	609.5	499.0
T55 Area2 (mm^2)	891.2	432.7	779.1	606.0	492.9
T55 MCA1 (mm^2)	270.2	77.8	359.3	162.1	185.0
T55 MCA2 (mm^2)	270.2	77.8	359.3	158.3	185.0
CBCT #	**25**	**40**	**59**	**75**	**88**
T73 Vol1 (mm^3)	28567.9	10637.8	22281.3	7367.1	16431.6
T73 Vol2 (mm^3)	27061.3	10034.2	22240.7	7427.4	17067.7
T73 Area1 (mm^2)	775.9	389.3	716.7	438.7	612.6
T73 Area2 (mm^2)	739.8	377.4	715.6	443.3	619.1
T73 MCA1 (mm^2)	328.5	119.9	190.6	94.2	280.3
T73 MCA2 (mm^2)	330.1	122.3	190.6	94.2	280.3
T55 Vol1 (mm^3)	23838.1	7949.4	16888.4	6435.6	13223.2
T55 Vol2 (mm^3)	22772.7	7778.6	16866.5	6488.1	13526.0
T55 Area1 (mm^2)	750.6	369.3	691.2	414.9	581.1
T55 Area2 (mm^2)	710.9	357.6	690.3	418.7	596.9
T55 MCA1 (mm^2)	300.0	103.4	172.5	80.2	252.2
T55 MCA2 (mm^2)	308.1	106.5	172.5	80.2	252.2

Appendix D: Statistical Analysis Tables

Age	All	Group I	Group II	p-value	Comments
N	100	50	50	0.054	Data is not normally distributed
mean	27	25	27		Method: Wilcoxon rank sum test
SD	7	7	7		Group medians are not significantly different
median	26	24	28		Shapiro-Wilk normality test
IQR	12	10	11		
Gender	**All**	**Group I**	**Group II**	**p-value**	
Female	46	27	19	0.109	Method: Pearson's Chi-squared test
	46%	27%	19%		Distributions among groups are equal
Male	54	23	31		
	54%	23%	31%		
Total	100	50	50		
	100%	50%	50%		

Horizontal Cephalometric Measures					
SNA	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.771	Data is not normally distributed;
mean	83.4	82.8	83.9		Method: Wilcoxon rank sum test
SD	3.9	3.1	4.6		Group medians are not significantly different
median	83.0	83.0	83.2		Shapiro-Wilk normality test
IQR	4.6	4.5	5.4		
SNB	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	<0.00001	Data is normally distributed

mean	78.4	80.4	76.4		Method: Welch Two Sample t-test
SD	4.3	3.2	4.3		Group averages are significantly different
median	78.3	80.2	76.3		Shapiro-Wilk normality test
IQR	6.0	4.6	5.3		
ANB	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	<0.00001	Data is not normally distributed;
mean	4.9	2.41	7.49		Method: Wilcoxon rank sum test
SD	2.8	1.01	1.35		Group medians are significantly different
median	4.8	1.63	6.50		Shapiro-Wilk normality test
IQR	4.4	1.48	1.60		
Wits	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	<0.00001	Data is normally distributed
mean	1.9	-1.0	4.8		Method: Welch Two Sample t-test
SD	3.9	2.3	3.0		Group averages are significantly different
median	1.5	-1.0	4.7		Shapiro-Wilk normality test
IQR	5.9	3.6	3.5		

Vertical Cephalometric Measures					
PFH:AFH	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.257	Data is normally distributed
mean	64.9	64.1	65.7		Method: Welch Two Sample t-test
SD	6.7	5.8	7.4		Group averages are significantly different
median	65.0	59.7	60.0		Shapiro-Wilk normality test
IQR	9.8	8.8	11.4		

FMA	All	Group I	Group II	p-value	
N	100	50	50	0.867	Data is normally distributed
mean	27.1	27.2	27.0		Method: Welch Two Sample t-test
SD	6.9	6.2	7.6		Group averages are significantly different
median	26.6	26.2	27.1		Shapiro-Wilk normality test
IQR	9.1	6.3	11.3		
SN-MP	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.738	Data is normally distributed
mean	35.7	36.0	35.4		Method: Welch Two Sample t-test
SD	8.1	7.0	9.1		Group averages are significantly different
median	35.1	35.1	35.0		Shapiro-Wilk normality test
IQR	10.7	8.4	12.2		

Airway Measurements - T73					
Total Volume	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.823	Data is not normally distributed;
mean	17,336	17,051	17,621		Method: Wilcoxon rank sum test
SD	7,272	6,646	7,906		Group medians are not significantly different
median	15,482	15,159	16,298		Shapiro-Wilk normality test
IQR	7,272	8,609	10,691		
COV	0.419469	0.389809	0.448638		

Airway Area	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.964	Data is not normally distributed;
mean	579.3	580.1	578.6		Method: Wilcoxon rank sum test
SD	169.6	158.0	182.1		Group medians are not significantly different
median	555.7	544.9	580.9		Shapiro-Wilk normality test
IQR	210.0	149.5	256.6		
COV	0.292757	0.272395	0.314677		
MCA	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.669	Data is not normally distributed;
mean	222.0	222.3	221.8		Method: Wilcoxon rank sum test
SD	123.5	113.8	133.7		Group medians are not significantly different
median	196.2	199.4	188.4		Shapiro-Wilk normality test
IQR	155.7	132.9	180.2		
COV	0.55633	0.511871	0.602957		

Airway Measurements - T55					
Total Volume	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.801	Data is not normally distributed
mean	13,420	13,132	13,709		Method: Wilcoxon rank sum test
SD	5,919	5,431	6,413		Group medians are not significantly different
median	11,510	11,405	12,508		Shapiro-Wilk normality test
IQR	7,223	7,187	6,987		
COV	0.44104	0.41354	0.46777		

Airway Area	All	Group I	Group II	p-value	
N	100	50	50		Data is not normally distributed
mean	553.3	548.2	558.3		Method: Wilcoxon rank sum test
SD	168.7	155.6	182.3		Group medians are not significantly different
median	524.2	500.1	570.3		Shapiro-Wilk normality test
IQR	221.4	160.1	277.5		
COV	0.30486	0.28378	0.326481		
MCA	**All**	**Group I**	**Group II**	**p-value**	
N	100	50	50	0.556	Data is not normally distributed
mean	186.5	187.5	185.5		Method: Wilcoxon rank sum test
SD	105.7	97.5	114.2		Group medians are not significantly different
median	165.0	169.1	152.6		Shapiro-Wilk normality test
IQR	153.4	138.1	162.4		
COV	0.56665	0.520232	0.615766		

Airway Measurements - T73 Low Angle Class II patients					
Total Volume	**Group I**	**Group IIa**		**p-value**	**Group IIa = FMA < 20**
N	50	9		0.712	Data is not normally distributed
mean	17,051	19,031			Method: Wilcoxon rank sum test
SD	6,646	10,115			Group medians are not significantly different
median	15,159	17,017			Shapiro-Wilk normality test
IQR	8,609	18,391			

Airway Area	Group I	Group IIa		p-value	
N	50	9		0.534	Data is not normally distributed
mean	580.1	609.4			Method: Wilcoxon rank sum test
SD	158.0	165.0			Group medians are not significantly different
median	544.9	665.7			Shapiro-Wilk normality test
IQR	149.5	314.7			
MCA	**Group I**	**Group IIa**		**p-value**	
N	50	9		0.891	Data is not normally distributed
mean	222.3	265.6			Method: Wilcoxon rank sum test
SD	113.8	212.7			Group medians are not significantly different
median	199.4	153.0			Shapiro-Wilk normality test
IQR	132.9	400.8			

Airway Measurements - T55 Low Angle Class II patients					
Total Volume	**Group I**	**Group IIa**		**p-value**	**Group IIa = FMA < 20**
N	50	9		0.591	Data is not normally distributed;
mean	13,132	15,413			Method: Wilcoxon rank sum test
SD	5,431	8,227			Group medians are not significantly different
median	11,405	12,966			Shapiro-Wilk normality test
IQR	7,187	14,668			

Airway Area	**Group I**	**Group IIa**		**p-value**	
N	50	9		0.520	Data is not normally distributed
mean	548.2	584.8			Method: Wilcoxon rank sum test
SD	155.6	162.7			Group medians are not significantly different
median	500.1	626.2			Shapiro-Wilk normality test
IQR	160.1	302.3			
MCA	**Group I**	**Group IIa**		**p-value**	
N	50	9		0.908	Data is not normally distributed
mean	187.5	228.3			Method: Wilcoxon rank sum test
SD	97.5	179.7			Group medians are not significantly different
median	169.1	136.4			Shapiro-Wilk normality test
IQR	138.1	338.9			

Airway Measurements - T73 High Angle Class II					
Total Volume	**Group I**	**Group IIb**		**p-value**	**Group IIb = FMA > 30**
N	50	20		0.314	Data is not normally distributed
mean	17,051	14,799			Method: Wilcoxon rank sum test
SD	6,646	5,243			Group medians are not significantly different
median	15,159	14,345			Shapiro-Wilk normality test
IQR	8,609	6,107			
Airway Area	Group I	Group IIb		p-value	
N	50	20		0.045	Data is not normally distributed
mean	580.1	501.0			Method: Wilcoxon rank

					sum test
SD	158.0	142.9			Group medians are significantly different
median	544.9	463.05			Shapiro-Wilk normality test
IQR	149.5	192.2			
MCA	**Group I**	**Group IIb**		**p-value**	
N	50	20		0.111	Data is not normally distributed
mean	222.3	173.2			Method: Wilcoxon rank sum test
SD	113.8	87.7			Group medians are not significantly different
median	199.4	169.45			Shapiro-Wilk normality test
IQR	132.9	166.25			

Airway Measurements - T55 High Angle Class II					
Total Volume	**Group I**	**Group IIb**		**p-value**	**Group IIb = FMA > 30**
N	50	20		0.387	Data is not normally distributed
mean	13,132	11,591			Method: Wilcoxon rank sum test
SD	5,431	4,163			Group medians are not significantly different
median	11,405	11,214			Shapiro-Wilk normality test
IQR	7,187	5,132			
Airway Area	**Group I**	**Group IIb**		**p-value**	
N	50	20		0.064	Data is not normally distributed
mean	548.2	480.2			Method: Wilcoxon rank sum test
SD	155.6	126.1			Group medians are not significantly different
median	500.1	432.8			Shapiro-Wilk normality test

IQR	160.1	175.8			
MCA	**Group I**	**Group IIb**		**p-value**	
N	50	20		0.085	Data is not normally distributed
mean	187.5	145.1			Method: Wilcoxon rank sum test
SD	97.5	79.7			Group medians are not significantly different
median	169.1	122.3			Shapiro-Wilk normality test
IQR	138.1	121.8			

Airway Measurements - T55 and Age Groups					
Total Volume	**All**	**Group I**	**Group II**	**p-value**	**Age Group <= 25**
N	50	28	22	0.608	Data is not normally distributed
mean	12,988	12,383	13,758		Method: Wilcoxon rank sum test
SD	5,479	4,550	6,506		Group medians are not significantly different
median	11,548	11,410	12,638		Shapiro-Wilk normality test
IQR	7,400	7,259	6,873		
Airway Area	**All**	**Group I**	**Group II**	**p-value**	**Age Group <= 25**
N	50	28	22	0.583	Data is normally distributed
mean	548.3	536.3	563.5		Method: Welch Two Sample t-test
SD	162.6	129.2	199.4		Group means are not significantly different
median	531.25	500.1	570.3		Shapiro-Wilk normality test
IQR	210.23	133.2	295.7		
MCA	**All**	**Group I**	**Group II**	**p-value**	**Age Group <= 25**
N	50	28	22	0.946	Data is not normally distributed

mean	178.0	173.6	183.6		Method: Wilcoxon rank sum test
SD	95.5	88.6	105.5		Group medians are not significantly different
median	152.5	156.2	150.2		Shapiro-Wilk normality test
IQR	142.4	145.0	131.2		
Total Volume	**All**	**Group I**	**Group II**	**p-value**	**Age Group > 25**
N	50	22	28	0.869	Data is not normally distributed
mean	13,852	14,084	13,670		Method: Wilcoxon rank sum test
SD	6,354	6,364	6,457		Group medians are not significantly different
median	11,495	11,335	12,107		Shapiro-Wilk normality test
IQR	7,250	7,548	6,116		
Airway Area	**All**	**Group I**	**Group II**	**p-value**	**Age Group > 25**
N	50	22	28	0.946	Data is not normally distributed
mean	558.2	563.4	554.2		Method: Wilcoxon rank sum test
SD	176.1	186.0	171.2		Group medians are not significantly different
median	512.5	497.9	567.3		Shapiro-Wilk normality test
IQR	220.2	169.1	233.8		
MCA	**All**	**Group I**	**Group II**	**p-value**	**Age Group > 25**
N	50	22	28	0.356	Data is not normally distributed;
mean	194.9	205.1	187.0		Method: Wilcoxon rank sum test
SD	115.3	107.3	122.5		Group medians are not significantly different
median	173.0	180.1	161.5		Shapiro-Wilk normality test
IQR	163.3	108.9	191.1		

Airway Measurements Repeated Measurements				
Total Volume	**First**	**Second**	**p-value**	
N	10	10	0.446	**Threshold = 73**
mean	18,191	18,024		Data is normally distributed
SD	7,343	7,391		Method: Paired t-test
median	17,640	17,893		Group means are not significantly different
IQR	12,120	13,010		Shapiro-Wilk normality test
CV	40.4%	41.0%		
Airway Area	**First**	**Second**	**p-value**	
N	10	10	0.825	**Threshold = 73**
mean	626.1	624.8		Data is normally distributed
SD	172.0	177.7		Method: Paired t-test
median	624.6	626.2		Group means are not significantly different
IQR	279.1	261.2		Shapiro-Wilk normality test
CV	27.5%	28.4%		
MCA	**First**	**Second**	**p-value**	
N	10	10	0.972	**Threshold = 73**
mean	216.7	216.7		Data is normally distributed
SD	104.1	104.3		Method: Paired t-test
median	194.6	194.6		Group means are not significantly different
IQR	152.0	151.3		Shapiro-Wilk normality test
CV	48.0%	48.1%		

Total Volume	**First**	**Second**	**p-value**	
N	10	10	0.574	**Threshold = 55**
mean	14,538	14,464		Data is normally distributed
SD	5,923	5,839		Method: Paired t-test
median	14,528	14,638		Group means are not significantly different
IQR	9,3610	9,749		Shapiro-Wilk normality test
CV	40.7%	40.4%		
Airway Area	**First**	**Second**	**p-value**	
N	10	10	0.528	**Threshold = 55**
mean	600.8	597.6		Data is normally distributed
SD	171.1	172.7		Method: Paired t-test
median	595.3	601.5		Group means are not significantly different
IQR	282.1	258.0		Shapiro-Wilk normality test
CV	28.5%	28.9%		
MCA	**First**	**Second**	**p-value**	
N	10	10	0.464	**Threshold = 55**
mean	196.3	197.0		Data is normally distributed
SD	96.6	97.4		Method: Paired t-test
median	178.8	178.8		Group means are not significantly different
IQR	147.6	146.3		Shapiro-Wilk normality test
CV	49.2%	49.4%		

Pearson Correlations for Intra-rater Reliability

All measurements significant at $p=<0.00001$

T73 Volume: 1st and 2nd measurements	$r = 0.996$	$r^2 = 0.992016$
T73 Area: 1st and 2nd measurements	$r = 0.996$	$r^2 = 0.992016$
T73 MCA: 1st and 2nd measurements	$r = 0.999$	$r^2 = 0.998001$
T55 Volume: 1st and 2nd measurements	$r = 0.998$	$r^2 = 0.996004$
T55 Area: 1st and 2nd measurements	$r = 0.996$	$r^2 = 0.992016$
T55 MCA: 1st and 2nd measurements	$r = 0.999$	$r^2 = 0.998001$

Spearman Correlations Between Volume, sagittal area and MCA

All measurements significant at p=<0.00001

GROUP I	
T55 Area and T55 MCA	rho=0.694
T55 Area and T55 Volume	rho=0.816
T55 Volume and T55 MCA	rho=0.885

GROUP II	
T55Area and T55 MCA	rho=0.699
T55 Area and T55 Volume	rho=0.854
T55 Volume and T55 MCA	rho=0.860

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